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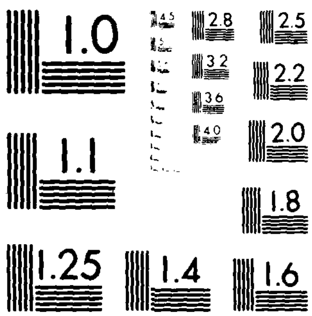

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A 4-week training program was undertaken by 15 untrained, unacclimated males who were divided into 3 groups matched on maximal aerobic capacity ($\dot{V}O_2$ max) and trained either in water or on land to determine how physical training (PT) in these different media affects heat tolerance. Subjects trained on a bicycle ergometer for 1 h/day, 5 days/week at 75% $\dot{V}O_2$ max, with the exercise intensity progressively increased to maintain a constant training stimulus. Group I exercised on land, while II and III exercised while immersed to the neck in water of either 32°C (II) or 20°C (III). Daily exercise increased

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core temperature (T_c) in I and II, but not in III. Training elicited similar increases ($\sim$15%) in $\dot{V}O_2$ max in the 3 groups. Before and after PT, all subjects exercised at $\sim$30% $\dot{V}O_2$ max for 3 h at 49°C, 20% rh. Compared to before training, I and II showed a decrease in final T_c and heart rate (HR) in the post-training heat exposure. Sweat rate (SR) increased 25% in II, but remained the same in I. Group III demonstrated a decrease in final HR but final T_c was higher than before training. SR did not increase in III and was lower than the other groups. It was concluded that PT can improve the cardiovascular response to dry heat without affecting thermoregulatory capacity. PT appears to enhance heat tolerance only if T_c is permitted to rise during exercise, thus stimulating the temperature-regulating center for heat dissapation.

EFFECTS ON HEAT TOLERANCE OF PHYSICAL TRAINING IN WATER AND ON LAND

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ABSTRACT

A 4-week training program was undertaken by 15 untrained, unacclimated males who were divided into 3 groups matched on maximal aerobic capacity ($\dot{V}O_2$ max) and trained either in water or on land to determine how physical training (PT) in these different media affects heat tolerance. Subjects trained on a bicycle ergometer for 1 h/day, 5 days/week at 75% $\dot{V}O_2$ max, with the exercise intensity progressively increased to maintain a constant training stimulus. Group I exercised on land, while II and III exercised while immersed to the neck in water of either 32°C (II) or 20°C (III). Daily exercise increased core temperature (T_c) in I and II, but not in III. Training elicited similar increases (~15%) in $\dot{V}O_2$ max in the 3 groups. Before and after PT, all subjects exercised at ~30% $\dot{V}O_2$ max for 3 h at 49°C, 20% rh. Compared to before training, I and II showed a decrease in final T_c and heart rate (HR) in the post-training heat exposure. Sweat rate (SR) increased 25% in II, but remained the same in I. Group III demonstrated a decrease in final HR but final T_c was higher than before training. SR did not increase in III and was lower than the other groups. It was concluded that PT can improve the cardiovascular response to dry heat without affecting thermoregulatory capacity. PT appears to enhance heat tolerance only if T_c is permitted to rise during exercise, thus stimulating the temperature-regulating center for heat dissipation.

Index terms: body temperature regulation; heat tolerance; physical training; water exercise; sweating; heat acclimation

INTRODUCTION

Prior physical training has been found to improve the tolerance of unacclimated individuals subsequently exposed to an acute heat stress (4, 10, 11, 23). However, the extent to which well-trained and physically fit subjects exhibit improved exercise-heat tolerance continues to be a disputed issue. The observation has been made that while physical training in a cool environment may enhance heat tolerance, the combination of physical exercise and heat exposure is necessary for full heat acclimation (30, 31).

Training is thought to confer some degree of heat acclimation since physiological changes associated with training could enhance an individual's response to heat stress. For example, training results in a lower heart rate and higher stroke volume at a given submaximal exercise intensity, thus stabilizing the cardiovascular system. Trained individuals will therefore be exercising at a lower percentage of their heart rate reserve when the strain of high ambient temperature is added to the physical activity. It also appears that fit individuals can maintain an adequate cardiac output sufficient to meet the combined metabolic and heat-dissipating requirements for a longer period of time than can unfit individuals (4, 5). In addition, presumably resulting from the rise in core temperature during exercise, sweat rate (10, 12, 23), sweat sensitivity (10, 15, 20), and sweating threshold (5, 11, 15) are all readjusted so that more rapid and adequate rates of heat dissipation can be achieved.

It is reasonable to assume that individuals who achieve their high level of aerobic fitness by swimming may not demonstrate improved exercise-heat tolerance since body temperature during exercise may not be raised. Thus, little stimulation of the heat-dissipating mechanisms can occur. Indeed, several studies have alluded to the poorer heat tolerance of water-trained

athletes compared to those trained on land (15, 23). However, training in water should lead to an improvement of the functional capacity of the cardiovascular system, resulting in higher circulatory heat conductance and perhaps a somewhat enhanced heat tolerance compared to untrained individuals.

This study of the effects of physical training on heat tolerance was undertaken to attempt to identify those training adaptations which influence an individual's tolerance to heat. Individuals were trained either in warm or cold water or on land. These media were selected since different responses could be expected from the exercise in the two water temperatures as compared to land. For example, while all groups may have been expected to improve their aerobic capacity with training, only the land group would show a substantial increase in body temperature and sweating during the exercise bouts. In addition, sweat sensitivity might be increased and body temperature at sweat onset decreased during land training. How these parameters would be affected by water training is not known.

METHODS AND PROCEDURES

Subjects: Fifteen (15) unacclimated and unconditioned young men were selected for participation in this study during the winter months. After having the procedures and potential risks explained to them, they gave their written consent to participate. The subjects were divided into three equal groups which were matched on the basis of initial maximal oxygen uptake ($\dot{V}O_2$ max) measurements, body surface area, and percentage body fat (TABLE 1). All three groups underwent an initial heat exposure and were then trained for one month either on land (Group I) or in 32°C (Group II) or 20°C (Group III) water.

INSERT TABLE I

Procedures: Prior to the initial heat exposure, anthropometric measurements, plasma volume and $\dot{V}O_2$ max were determined at a thermoneutral temperature (22°C). Additionally, local sweat rate, for determination of sweat sensitivity and sweating threshold, was measured at 25°C while the subjects pedaled a bicycle ergometer at ∿ 65% $\dot{V}O_2$ max. All subjects then underwent the first heat stress test which consisted of a 3-h exposure to a dry bulb/wet bulb combination of 49°C/28°C, with a wind speed of 1 $m \cdot s^{-1}$. Each h of exposure was divided into 50 min walking on a level treadmill at 30% $\dot{V}O_2$ max, followed by 10 min of resting. Clothing during the heat exposure consisted of shorts, socks and sneakers.

Following the initial heat stress test, the subjects were trained for one month on a bicycle ergometer either on land (Group I) or while immersed to the neck in 32°C (Group II) or 20°C (Group III) water. A Monark ergometer, modified for underwater use (27), was utilized for the training in water. Training consisted of pedaling the ergometer at 75% of the initial cycling $\dot{V}O_2$ max, as determined on land, for one hour per day, 5 days per week. The exercise intensity was readjusted each week to maintain the same relative intensity of exercise as training progressed. This weekly readjustment was achieved in the land group by having the subjects exercise daily at a heart rate (HR) of 170 $beats \cdot min^{-1}$. In water, however, the HR/$\dot{V}O_2$ curve is shifted to the right (18), so that HR's of 160 and 150 $beats \cdot min^{-1}$ represented training intensities of 75% $\dot{V}O_2$ max for the warm and cold water groups, respectively. Heart rate was continuously measured during all training sessions, while rectal temperature and total body sweat rate were determined at least once each week during the month-long training period.

Following training, $\dot{V}O_2$ max, plasma volume, and local sweat rate were again measured. The subjects then underwent a post-training 3-h heat stress test under the same environmental conditions and work/rest schedule. A 10-d

heat acclimation then ensued, during which the subjects were exposed to 49°C/28°C for 2 h per day. After acclimation, the final determinations of $\dot{V}O_2$ max, plasma volume and local sweat rate were made. The post-acclimation heat stress test was then performed.

For all heat exposures, HR, rectal temperature (T_{re}) and mean skin temperature ($\bar{T}_{sk}$) were continuously recorded. Exposure was terminated if any of the following occurred: HR > 180 beats·min^{-1} during exercise; T_{re} > 39.5°C; dizziness, nausea, dry skin.

<u>Measurements</u>: Maximal oxygen uptake was determined on the bicycle ergometer by a method modified from Kamon (17). During all maximal testing and for all training days and heat exposures, oxygen uptake was determined by the open circuit technique. One-minute expired air samples were collected in Douglas bags and subsequently analyzed for O_2 and CO_2 content with an Applied Electrochemistry O_2 Analyzer and a Beckman LB II CO_2 Analyzer, respectively. The volume of air was measured in a Tissot spirometer and then converted to STPD.

Rectal temperature was measured with a Y.S.I. thermistor probe inserted 10 cm beyond the anal sphincter. Skin temperature was measured with copper-constantan thermocouples attached to three sites, chest, calf, and forearm. Mean weighted skin temperature was then calculated according to Burton (2). Heart rate was measured with a Hewlett-Packard telemetry system. Total body sweat and evaporation rates were determined by the changes in nude and clothed weights, respectively, after adjusting for water intake. Weight loss was measured on a K-120 Sauter precision balance with an accuracy of $\pm$ 10 g. Ad libitum water intake was encouraged during all heat exposures.

Local sweat rate ($\dot{m}_{sw}$) was determined prior to each heat stress test by resistance hygrometry. Internal temperature was measured in the esophagus at the level of the heart. An 11 cm^2 capsule was attached to the chest for

determination of $\dot{m}_{sw}$. The subject then pedaled a bicyle ergometer for 15-20 min at ∿ 65% $\dot{V}O_2$ max in an ambient temperature of 25°C.

The day before each heat stress test, plasma volume was measured using Evans Blue dye. Hematocrit was determined in triplicate by microcentrifugation. Hemoglobin was measured by the cyanmethemoglobin method. All blood samples were drawn from the antecubital vein after the subject had been quietly seated for 30 min at a room temperature of 22°C.

Statistical Treatment: All variables were analyzed with a mixed factorial analysis of variance. Tukey's multiple comparison procedure was utilized as a follow-up if significant ($p<0.05$) F-valves were found.

RESULTS

The initial $\dot{V}O_2$ max on the bicycle ergometer did not significantly differ among the three groups with the mean (± S.E.) of all groups equal to 3.08 ± 0.10 $l \cdot min^{-1}$. Following the month-long training period on the bicycle ergometer either on land or in water, $\dot{V}O_2$ max, as measured on the bicycle on land, was significantly increased in all groups. Group I demonstrated a 16% increase in $\dot{V}O_2$ max compared to increases of 13 and 15% for the groups exercising in warm and cold water, respectively (post-training $\dot{V}O_2$ max = 3.57 ± 0.19, 3.57 ± 0.22, and 3.45 ± 0.23 $l \cdot min^{-1}$ for Groups I, II, and III, respectively).

During each training session, rectal temperatures rose ∿ 1.1°C in the subjects exercising on land. The warm water group demonstrated an average increase in T_{re} of 0.6°C per hour while the cold water group showed a steady decline in T_{re}, the magnitude of which appeared to depend upon the initial T_{re} and the metabolic rate. Total body sweat rate for each training session averaged ∿ 600 $g \cdot m^{-2} \cdot h^{-1}$ in Group I and 200 $g \cdot m^{-2} \cdot h^{-1}$ in Group II. No sweat loss was measurable in Group III.

Prior to training, the subjects in Group I were able to tolerate the initial heat exposure for 174 $\pm$ 4 min before reaching the objective criteria for termination of the test. Groups II and III had similar tolerance times of 132 $\pm$ 25 min. Due to the large individual variation, there was no significant difference between the tolerance times of Group I and Groups II and III. Following training, all individuals in the land group were able to tolerate the heat stress for 3 h. The warm water group demonstrated an increase in tolerance time of 36 min while the cold water group averaged a tolerance time that was 10 min less than before training ($p>0.05$). After the 8-day acclimation, all subjects were able to complete the full 3 h of the final heat stress test.

The mean values of final T_{re} and $\bar{T}_{sk}$ for each group for the pre-training, post-training and post-acclimation heat stress days are presented in Figure 1. Before training, there were no significant differences among the groups in the final values of T_{re}. Following training, the final T_{re} showed a decline of 0.53°C and 0.46°C in Groups I and II, respectively ($p<0.05$). Group II demonstrated a lower post-training value of T_{re} despite the increase of 36 min in exposure time. Group III demonstrated a significant increase of 0.30°C in final T_{re} following training even with the reduction in tolerance time. Final values of T_{re} for Group III were significantly higher than Groups I and II in the post-training heat stress test. After heat acclimation, final T_{re} was 38.1°, 38.3° and 38.4°C in Groups I, II, and III, respectively ($p>0.05$). These values represented significant reductions in all three groups from the post-training values of T_{re}.

INSERT FIGURE 1

Mean skin temperature was greater than 37°C in all groups prior to training. (Figure 1). In the post-training heat stress test, Groups I and II demonstrated

significant reductions of 0.9°C in final $\bar{T}_{sk}$. The final $\bar{T}_{sk}$ of 37.5°C in Group III, however, was no different from the value found during the first heat exposure. Following heat acclimation all groups had a final $\bar{T}_{sk}$ of about 36°C, which represented a significant decline from the post-training value.

Final HR was found to decrease significantly in all three groups following physical training, as seen in Figure 2. The greatest decline, however, was evident in Group I which demonstrated a reduction of 29 beats·min^{-1} in final HR ($p<0.05$). Groups II and III showed declines in final HR of 14 and 18 beats·min^{-1}, respectively ($p<0.05$). Heat acclimation served to further significantly reduce final HR to similar levels in all three groups (∿ 125 beats·min^{-1}).

INSERT FIGURE 2

Figure 3 presents the mean values of sweat rate for the three heat stress tests. Before training, the sweat rate of 506 g·m^{-2}·h^{-1} for Group I was significantly higher than the mean sweat rate of Group III (437 g·m^{-2}·h^{-1}). There were no other significant differences in initial sweat rate. Following training, only Group II demonstrated a significant increase (25%) in total body sweat rate. With heat acclimation, sweat rate was not significantly increased in either Groups I or II. In Group III, however, the combination of training plus heat acclimation served to significantly increase the sweat rate by 25% over that found during the pre-training heat stress test.

INSERT FIGURE 3

Total body heat storage was calculated from the changes in T_{re} and $\bar{T}_{sk}$: $S = [0.97 \times wt \times (0.8\ \Delta T_{re} + 0.2\ \Delta \bar{T}_{sk})] \div$ S.A. The values were standardized for the time each individual was able to tolerate the heat exposure for the

first and second heat stress exposures. Figure 4 demonstrates that the values of heat storage for the initial heat stress test were similar in all groups ($p>0.05$). Following training, heat storage diminished significantly in both Groups I and II but remained the same in Group III. Heat acclimation served to decrease the rate of heat storage in all groups compared to post-training values ($p<0.05$) and also to eliminate the differences that existed among the groups following training.

INSERT FIGURE 4

TABLE 2 presents a comparison of the physiological adaptations occurring in the three groups as a result of training and training plus heat acclimation. In Groups I and II, T_{re} declined by $\sim$ 1.0 C° from the first to the third heat stress test. Half of this decline in final T_{re} could be attributable to the training program. In Group III, however, the entire decline of 0.83°C in final T_{re} resulted from the 8-d acclimation procedure. Approximately 2/3 of the 47 beats$\cdot$min^{-1} decline in final HR occurred as a result of training on land. On the other hand, only 1/3 of the total decline in final HR was evident following training in Groups II and III. The larger decline was attributable to heat acclimation. As with T_{re}, 50% of the reduction in final $\bar{T}_{sk}$ occurred following training in Groups I and II while Group III showed its entire reduction in $\bar{T}_{sk}$ following heat acclimation. Sweat rate did not increase appreciably in Group I as a result of either training or acclimation. Group II demonstrated almost 100% of its total increase in sweat rate as a result of training in warm water. With Group III, the slight increase in sweat rate that occurred with training (53 $g \cdot m^{-2} \cdot h^{-1}$) and with acclimation (56 $g \cdot m^{-2} \cdot h^{-1}$) represented a significant increase over the pre-training values.

INSERT TABLE 2

TABLE 3 presents a summary of the changes in local sweat rate which occurred following training and acclimation. Due to the large individual variation, no significant differences were obtained in any of the measured parameters. Some trends, however, were in evidence. The land group tended to demonstrate an increase in the slope of the $\dot{m}_{sw}$/core (esophageal) temperature relationship following training, but not heat acclimation. No change in the temperature at sweat onset was evident in Group I following training; but after acclimation, a slight reduction in sweat threshold was observed. Group II tended to show an increase in sweat sensitivity with both training and acclimation. The sweat threshold declined somewhat following training but showed no change following acclimation. Group III showed no change in slope or threshold following training. After acclimation however, sweat sensitivity was increased and temperature at sweat onset was decreased.

INSERT TABLE 3

The changes in resting plasma volume ($ml.kg^{-1}$) following training and heat acclimation are presented in Figure 5. Initial plasma volume was similar in the three groups with a mean value of 44.5 $ml \cdot kg^{-1}$. Following training, plasma volume was slightly increased in all groups, but this was not a significant finding. Again, no group difference was evident in the post-training values. The mean post-training plasma volume was 46.8 $ml \cdot kg^{-1}$ ($\sim$ 5% greater). Acclimation served to expand resting plasma volume in all groups. Thus, the difference between the pre-training and post-acclimation values of resting plasma volume was significant with a mean increase to 51.1 $ml \cdot kg^{-1}$. This represented an average expansion of 15% from the initial heat exposure before training to the post-acclimation heat stress test.

INSERT FIGURE 5

DISCUSSION

An intensive training program to induce some degree of heat acclimation is more appealing for determining the effects of physical conditioning on heat tolerance than using trained and untrained subjects. In the first place, the problem of body size, and hence rate of metabolic heat production, would be sidestepped since the same subjects would be heat-exposed before and after training. In addition, the subjects would be acting as their own controls. However, the use of a training program has not always proven successful in stimulating heat acclimation. Mild-to-moderate intensity training programs have enhanced heat tolerance only marginally (28, 29, 30), while more intense training regimens presumably provided a more powerful stimulus to the thermoregulatory system and thus led to a greater improvement in heat tolerance (10, 11, 15, 20). It appears that the best improvement in heat tolerance as a result of physical training is brought about by: 1) intensive continuous or interval training at a level requiring >50% $\dot{V}O_2$ max; 2) 8-12 weeks of training; and 3) a training program which elicits an increase of 15-20% in the individual's $\dot{V}O_2$ max (22). In the present study, the individuals were trained using an intensive continuous endurance training program at ∿75% $\dot{V}O_2$ max for 20 days. The improvement in $\dot{V}O_2$ max for all groups, whether exercising on land or in warm or cold water, averaged 15%. Thus, based on previous literature, it would appear that these 15 trained individuals would have a high probability of demonstrating at least partial heat acclimation after training.

The results of this study represents a continuum of improvement in heat tolerance as a consequence of physical training. Group I, which trained conventionally on land, demonstrated the most improved physiological responses in the post-training heat stress test. Half of the total reduction in final

T_{re} and $\bar{T}_{sk}$ and 62% of the decrease in HR occurred as a result of training on land. In the warm water group, T_{re} and $\bar{T}_{sk}$ also declined by 50% of the total (training and acclimation) reduction following training. Heart rate, however, showed only 35% of the total decrease occurring as a result of training. With Group III, virtually no improvement in heat tolerance was noted other than an 18 beats$\cdot$min^{-1} decrease in final HR which represented 35% of the total reduction in final HR resulting from training and acclimation.

Other than the media in which the groups exercised, the main difference among the three groups during training was in the degree to which body temperature, and hence sweat rate, was permitted to increase during the daily exercise bouts. Again, somewhat of a continuum was presented. Group I demonstrated the greatest rise in T_{re} (1.1°C/h), with Group II showing about half that elevation (0.6°C/h) and Group III showing no increase in body temperature with exercise due to the convective cooling capacity of the cold water. It appears then, that following an endurance-type training program, the extent of the improvement in heat tolerance, as measured by T_{re} and completion time, is directly related to the degree of elevation of core temperature during exercise. This is analogous to the finding that the level of heat acclimation depends upon the degree of body hyperthermia, with the higher target core temperatures eliciting better physiological adaptation to a subsequent heat stress (7). Thus, the lack of improvement in heat tolerance in the cold water group could be ascribed to the lack of rise of internal temperature during the exercise bouts. Although the warm water group produced only half the increase in core temperature during training as did the land group, this appeared adequate to stimulate the heat-dissipating mechanisms so that rates of heat storage (Fig. 4) and final T_{re} (Fig. 1) were similar in both the land and warm water groups in the post-training heat exposure.

While the reduction in T_{re} following training appeared to depend upon the elevation of core temperature, the improvement in HR may have resulted from a more stable cardiovascular system as a consequence of training. The reduction in HR during the post-training heat exposure suggests that the individuals had a larger stroke volume during exercise in the heat. Following training, stroke volume is enhanced or sustained during exercise in the heat, probably as a result of the maintenance of plasma volume (26). It has been found that trained men (26) and women (4, 5) gain more protein during the first hour of exercise in the heat compared to untrained controls and thus are able to increase their plasma volume (24). With their expanded blood volume, trained individuals are able to maintain a sufficient stroke volume and cardiac output for adequate transfer of heat to the periphery while delivering sufficient quantities of oxygen to the exercising muscles.

Following training, the quantitative difference in the reduction in HR between Group I and Groups II and III can perhaps be explained by different mechanisms. In Group II, sweat rate was significantly increased over the pre-training value. While body weight did not decrease to any critical level of dehydration (mean percentage change of body weight = -1.2%) it is possible that the fluid lost as sweat may not have been completely replaced by water ingestion. The decrease in body fluid would be reflected in the vascular compartment as a reduction in plasma volume (6, 25). As plasma volume is diminished, venous return would be reduced and stroke volume would decrease thus increasing HR (32).

With Group III, the mechanism behind the higher HR than Group I may have been a factor of tissue conductance. Mean skin temperatures were significantly higher in Group III during the heat exposure, perhaps suggesting a higher skin blood flow. It has been shown that swimmers have a higher tissue

conductance than runners (19) and are thought to have developed better peripheral vasocontrol. They can therefore transport more heat to the surface via vasomotor regulation than can runners (19). A higher skin conductance implies a higher blood flow through the peripheral beds at the expense of the central blood volume. As central blood volume decreases, venous return, and hence stroke volume, also decreases precipitating a reciprocal increase in HR.

In the present study, total body sweat rate was not significantly increased as a result of land or cold water training. Although some investigators have shown an increase in sweat rate with training (15), the majority of studies suggest that training in a cool environment does not necessarily increase the sweat rate of men subsequently exposed to heat (10, 28, 29, 31). The cold water group would not have been expected to show an increase in sweat rate since both body and skin temperatures did not increase during training. Hence neither local nor central stimulation for sweat production was present.

The individuals training in warm water, however, did demonstrate a significant increase in their total body sweat rate in the post-training heat stress test. This increase can perhaps be explained as a local phenomenon of sweat gland training. It has been shown that if body temperature is raised while one arm is immersed in warm water (43°C) and the other arm kept within a vapor barrier suit for 2h/day for 15 days, the immersed arm will demonstrate a greater increase in sweat rate during a standardized sweating determination (8). Immersion up to the neck in 35°C water for 4 hours prior to a heat exposure was also shown to act as a local stimulation to increase total body sweat rate during a subsequent sweating determination (1). It appears that both local and body heating is necessary to elicit this increase in local sweat rate since immersion in warm water with core

temperature kept cool did not produce as dramatic an increase in sweat rate during the sweating test (8).

It is conceivable that a diminishment of sweat suppression may have played a role in the augmentation of sweating following warm water training. Fox et al (9) have demonstrated that continued exposures to hot-wet environments during acclimation leads to a decrease in the suppression of sweating found during standardized sweating tests conducted before any heat exposure. With hot-dry acclimation, however, the suppression of sweat with time is enhanced in a post-acclimation sweating test compared to before heat treatments. Hence, sweat rate may appear to be augmented when in fact, the warm water-trained group experienced less of a decrease in sweat rate during the three-hour heat exposure due to their training in warm water which could have produced similar responses as acclimation to hot-wet conditions.

Local sweat rate results indicated an increase in the sensitivity of the sweating mechanism to changes in core temperature in both the land and warm water groups following training (TABLE 3). Previous investigations have also demonstrated an augmentation in sweat sensitivity with conventional land training (10, 15, 20). The local effect of exercising in warm water, as noted above, could have accounted for the apparent increase in sweat sensitivity in the warm water group. As expected, since no local stimulation was apparent in the cold water group, no improvement in sweat sensitivity was evident.

Plasma volume has been found to expand following physical training (16, 21) and heat acclimation (14, 25). In the present study, resting values of plasma volume were not significantly increased in any of the groups although all three tended to demonstrate somewhat of a plasma volume expansion following training. The combination of training plus heat acclimation served to increase the resting

plasma volume by an average 15% over the pre-training values. It is interesting to note that in a recent study by Convertino et al (3), it was concluded that 40% of the exercise-induced plasma volume expansion could be accounted for by the hyperthermia associated with exercise. In this study, the land group, which demonstrated the largest daily rise in core temperature, actually showed the least (3.2%) expansion of their plasma volume following training. Group III, which showed a decline in daily core temperature, was found to expand their resting plasma volume by an average of 6.7%. Perhaps the daily hemodilution experienced by Groups II and III during the one hour of exercise in water (13) could partially explain the slight increase in resting plasma volume noted at the end of the month-long training period.

In conclusion, it appears that the cardiovascular component to exercise-heat tolerance can be enhanced without improving thermoregulatory function. A rise in core temperature during exercise, which stimulates the heat-dissipating responses, appears necessary for physical training to significantly improve tolerance to a hot, dry environment.

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1. The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

2. Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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TABLE 1. Physical characteristics of the subjects (values are mean ± S.D.).

Group	n	Age	Height	Weight 1*	Weight 2**	Body Fat	A_D
		yr	cm	kg	kg	%	m^2
I	5	23.2	177.2	68.8	68.6	17.1	1.85
(Land)		±4.7	± 8.3	±13.9	±11.3	± 4.1	±0.21
II	5	20.8	170.5	72.3	71.5	15.6	1.83
(T_w=32°C)		±1.8	± 9.4	±14.7	±15.5	± 4.1	±0.23
III	5	23.0	177.3	66.0	65.5	13.2	1.81
(T_w=20°C)		±4.1	± 6.2	± 5.7	± 5.5	± 4.1	±0.05

* Represents pre-training body weight

** Represents post-training body weight

TABLE 2. Comparison of changes in T_{re}, HR, $\bar{T}_{sk}$ and SR resulting from training (HS1→HS2) and from training and acclimation (HS1→HS3) in the land (I), warm water (II) and cold water (III) groups.

	HS1→HS2	HS1→HS3
T_{re} (°C)		
I	-0.53	-1.00
II	-0.46	-1.02
III	+0.30	-0.83
HR (beats·min^{-1})		
I	-29	-47
II	-14	-40
III	-18	-51
$\bar{T}_{sk}$ (°C)		
I	-0.85	-1.59
II	-0.91	-1.75
III	+0.15	-1.29
SR (g·m^{-2}·h^{-1})		
I	+ 10	+ 29
II	+124	+127
III	+ 53	+109

TABLE 3. Sweat sensitivity (slope) and esophageal temperature at sweat onset (threshold) in the land (I), warm water (II) and cold water (III) groups determined before and after training and following acclimation.

	Slope ($mg \cdot min^{-1} \cdot cm^{-2} \cdot °C^{-1}$)			Threshold (°C)		
	I	II	III	I	II	III
Pre-training	0.91 ± 0.38	0.98 ± 0.28	1.10 ± 0.32	37.36 ± 0.24	37.22 ± 0.06	37.46 ± 0.13
Post-training	1.78 ± 0.44	1.35 ± 0.36	1.35 ± 0.21	37.68 ± 0.22	36.99 ± 0.26	37.34 ± 0.10
Post-acclimation	1.81 ± 0.43	1.88 ± 0.17	1.87 ± 0.57	37.24 ± 0.09	36.92 ± 0.22	36.90 ± 0.19

FIGURE LEGENDS

Figure 1. Comparison of final rectal and skin temperature (mean $\pm$ S.E.) for the land (I), warm water (II), and cold water (III) groups before (Heat Stress 1) and after physical training (Heat Stress 2), and following heat acclimation (Heat Stress 3).

Figure 2. Comparison of final heart rate (mean $\pm$ S.E.) for the land (I), warm water (II), and cold water (III) groups before (Heat Stress 1) and after physical training (Heat Stress 2) and following heat acclimation (Heat Stress 3).

Figure 3. Comparison of total body sweat rate (mean $\pm$ S.E.) for the land (I), warm water (II) and cold water (III) groups before (Heat Stress 1) and after physical training (Heat Stress 2) and following heat acclimation (Heat Stress 3).

Figure 4. Comparison of total heat storage (mean $\pm$ S.E.) for the land (I), warm water (II) and cold water (III) groups before (Heat Stress) 1 and after physical training (Heat Stress 2) and following heat acclimation (Heat Stress 3).

Figure 5. Comparison of resting plasma volume (mean $\pm$ S.E.) for the land, warm water and cold water groups before and after physical training and following heat acclimation.

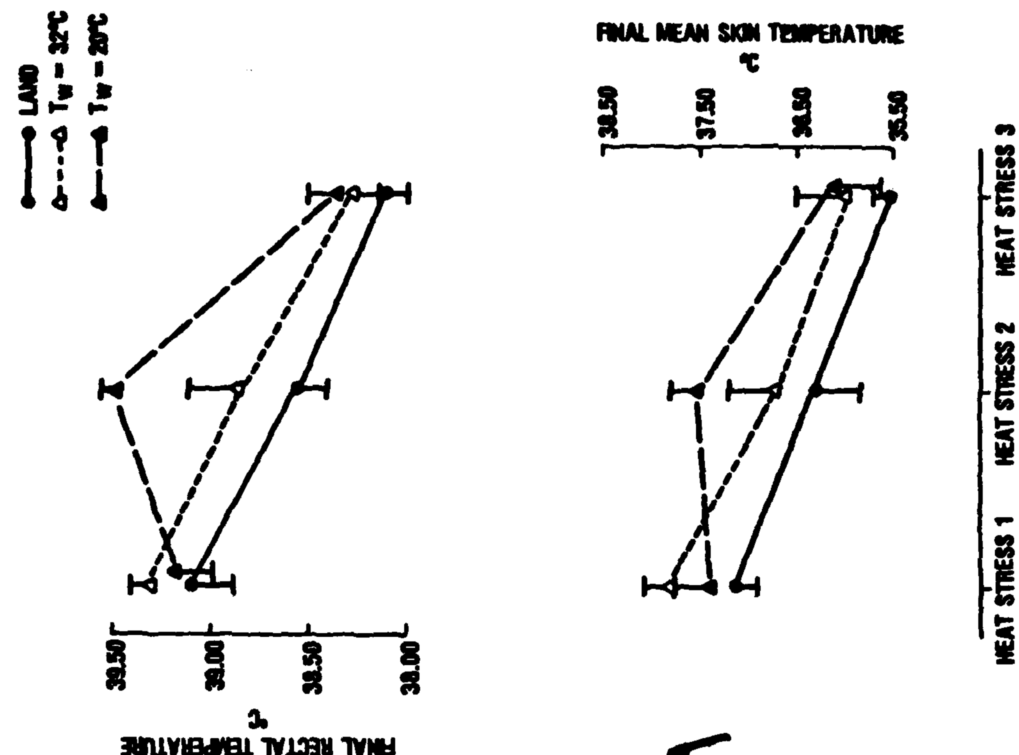

FINAL MEAN SKIN TEMPERATURE
°C
38.50
37.50
36.50
35.50
LAND
T_W = 32°C
T_W = 20°C
FINAL RECTAL TEMPERATURE
°C
39.50
39.00
38.50
38.00
HEAT STRESS 1
HEAT STRESS 2
HEAT STRESS 3

Fig 1

Fig 2

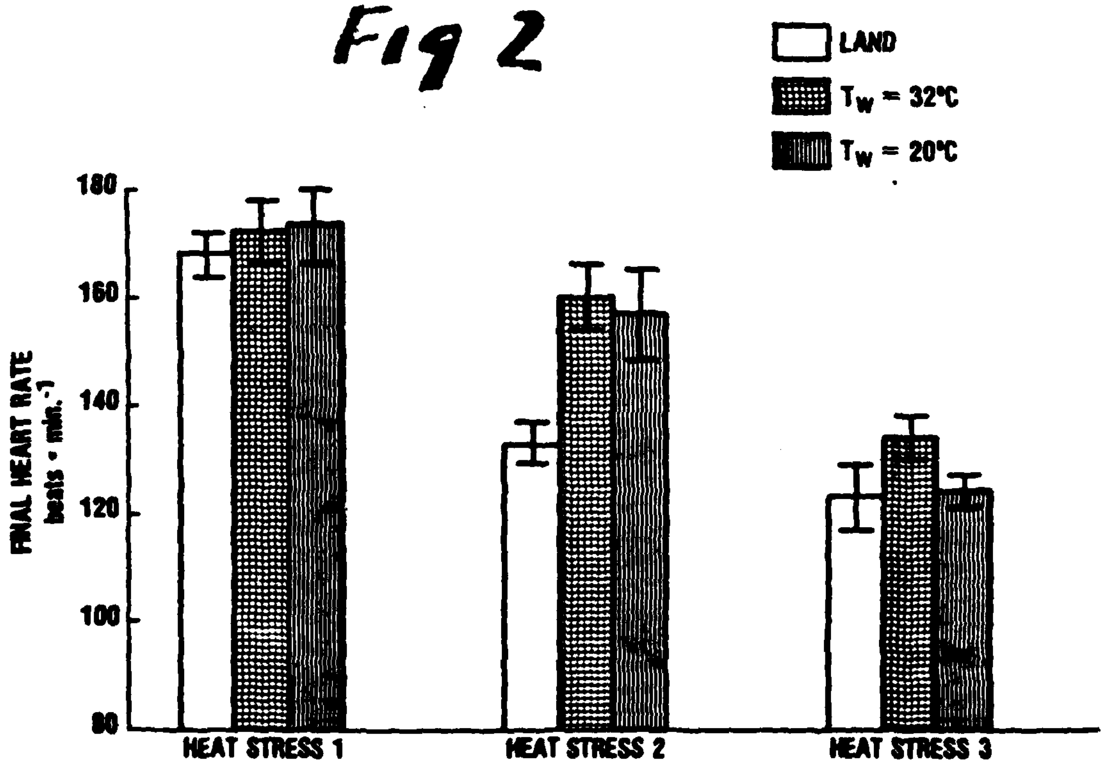
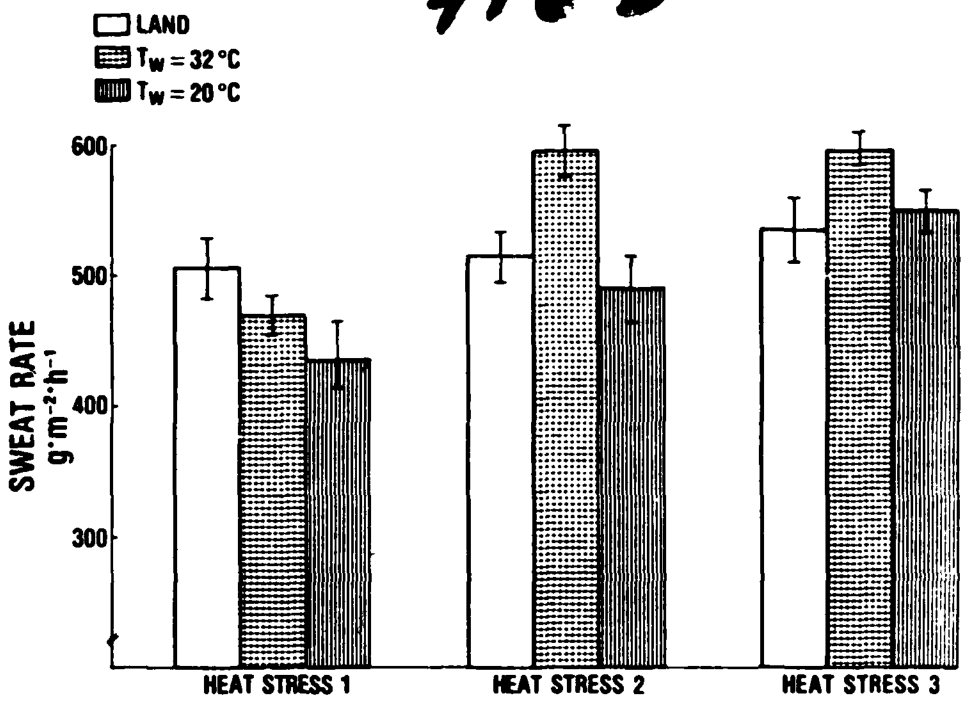
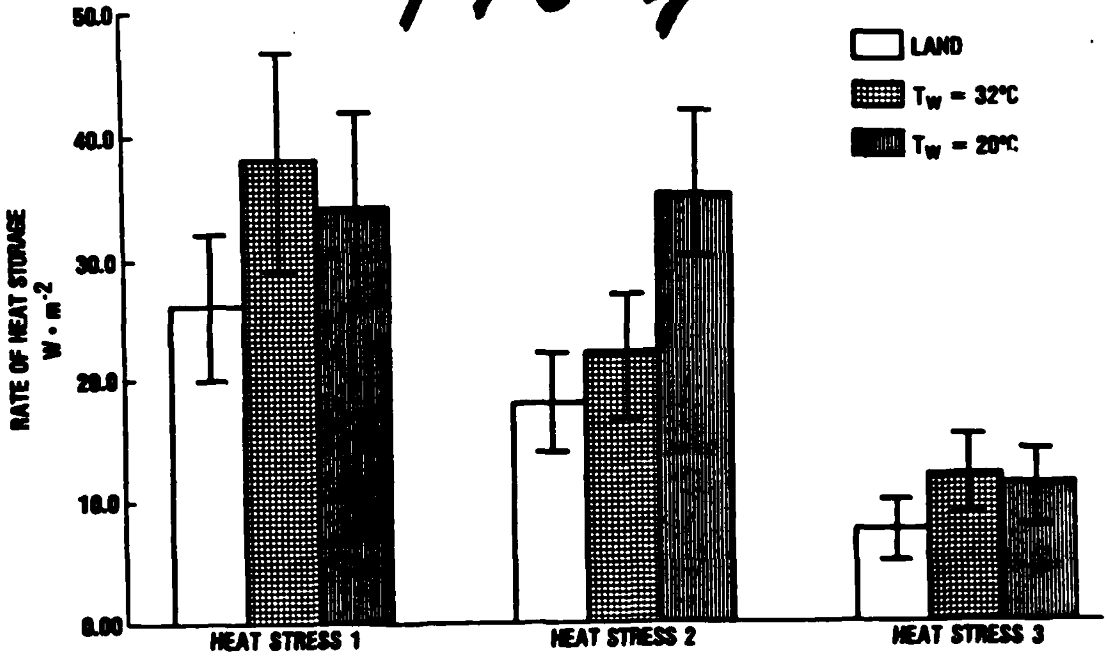

LAND
T_W = 32°C
T_W = 20°C
FINAL HEART RATE
beats · min.$^{-1}$
180
160
140
120
100
80
HEAT STRESS 1
HEAT STRESS 2
HEAT STRESS 3

FIG 3



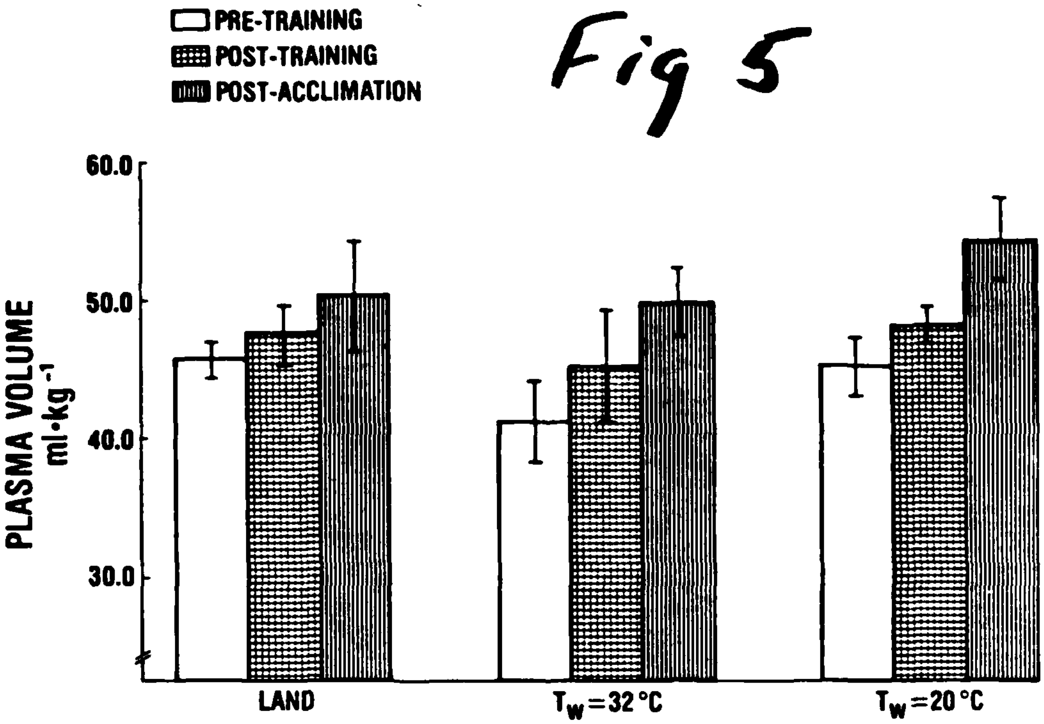
LAND
T_W = 32 °C
T_W = 20 °C
600
500
400
300
SWEAT RATE
g·m⁻²·h⁻¹
HEAT STRESS 1
HEAT STRESS 2
HEAT STRESS 3

FIG 4



50.0
40.0
30.0
20.0
10.0
0.00
RATE OF HEAT STORAGE
W · m⁻²
LAND
T_W = 32°C
T_W = 20°C
HEAT STRESS 1
HEAT STRESS 2
HEAT STRESS 3

Fig 5


PRE-TRAINING
POST-TRAINING
POST-ACCLIMATION
PLASMA VOLUME
ml·kg-1
60.0
50.0
40.0
30.0
LAND
Tw=32°C
Tw=20°C

1. The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

2. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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